Swedish J. agric. Res. 13: 157–165, 1983

Soil Animals in Relation to Agricultural Practices and Soil Productivity

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Abstract. About 15 old field experiments which started in the 1950s with different crop rotations and manuring or fertilizing systems were used for an extensive study of soil fauna in arable land in Sweden. A detailed review of the literature especially from the Nordic countries was also carried out.

The numerical density of most fauna groups is lower in Swedish arable soil than in grassland soils or forest soils. There is a long-term stability but a short-term variation of abundance caused by different agricultural treatments as well as by abiotic factors.

Continuous cereal cropping with removal of the straw over a 25-year period or more has reduced number and biomass of the soil fauna compared with previous mixed farming. Biological activity steadily decreases with organic matter levels when annual crops are regularly grown in the same soil. Negative effects of intensive arable farming on such beneficial organisms as earthworms can be minimized by practices which conserve or build up soil organic matter. Incorporation of crop residues, and farmyard manure, into the soil is most important for an abundant and diverse fauna. Legumes and well fertilized grass leys in the rotation also have high abundances in comparison with cereal cropping only.

High amounts of nitrogen fertilizer to grass ley did not negatively affect faunal densities except just after application on very dry soils. Herbicides such as fenoxi acids and dinitro-compounds caused a reduction of numerical density in grassland as an indirect effect of the change of plant cover.

INTRODUCTION

The productivity of agricultural and forest soils is reflected in the biomass of above- and below-ground parts of plants. High production is dependent on a healthy soil and this, in turn, is contingent on good physical, chemical and biological factors. However, little is known about the biological properties and even less about important interactions between biological and other factors in arable soils in northern Europe. This is in contrast with the very comprehensive research on soil organisms in different types of forest soils, natural grasslands (e.g. Persson & Lohm, 1977) and other natural biotopes. A good number of these studies are reported in proceedings of the international conferences on soil biology (e.g. Vanêk, 1975; Dindal, 1980).

In this paper, I will summarize data from studies, particularly in northern Europe, on basic and applied ecology of agricultural lands and then report on recent and on-going work being carried out at the Swedish University of Agricultural Sciences (SLU). The latter studies are some of the few interdisciplinary ones which combine research on interactions between biological, physical and chemical factors, on one hand, and crop production on the other hand.

Background

A particular agricultural crop together with the soil in which it grows and soil air and water can be considered to be a cropping system. Agricultural research at SLU has largely focused on plant production and several of the investigations on crop rotation and soil fertility trials started in the early 1950's. It has been clearly shown (e.g. Jansson, 1975) that soil fertility can be maintained at a high level by means of inorganic fertilizers. However, the question of long term consequences of intensive agriculture, in which organic matter is not recycled and where soil carbon levels are steadily decreasing, remains. This is particularly so on farms where leys play little or no role.

Problems involving different cropping systems have been carefully discussed in recent reports on rotation experiments (Ebbersten, 1980; Nyström, 1976; Kornher & Nyström, 1974; Olsson, 1976). It is well known that yield of arable crops is influenced by the crops previously cultivated in the field. Cultivation of the same crop year after year leads to lower average yields of the crop in question than if it is cultivated in a rotation with other crops. The extent of this effect of the preceding crop varies for different crops. The reports cited above have clearly demonstrated that the residual effect of rotation (that is the effect of the preceding crop) is basically due to plant pathogens. The negative

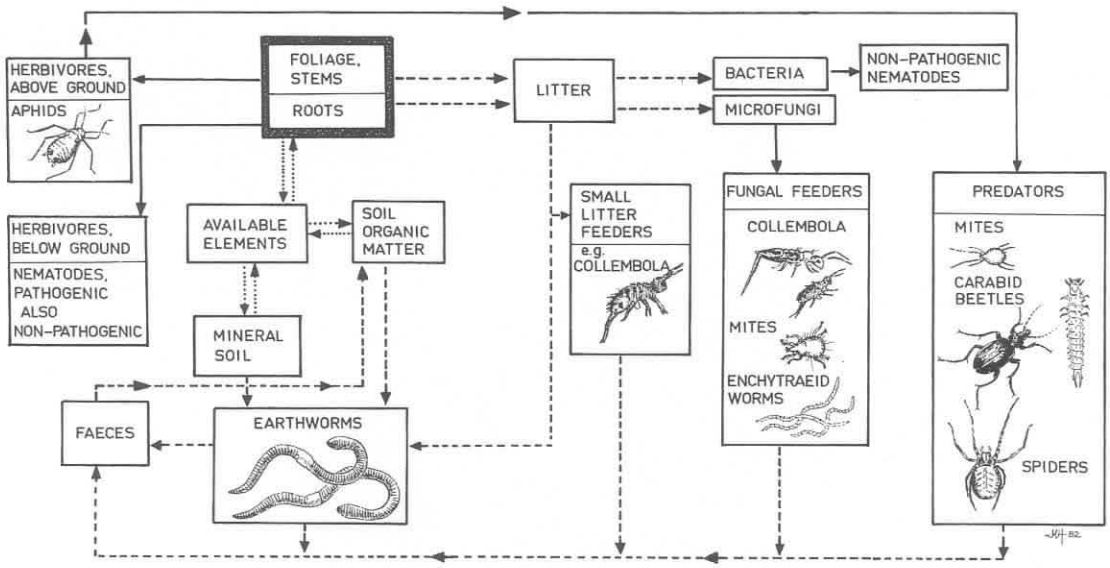

Fig. 1. Some food web relationships in an agricultural cropping system. For simplicity, scavengers not shown. (Drawing: Martin Holmer.)

influence of plant parasites is maximized by monoculture but is checked if other crops are occasionally alternated with the main crop.

A large part of the plant parasitic load on a crop in mono-cropping is caused by fungus diseases. The root rot diseases of cereals may cause 10–20 per cent reduction in yield in monocultures of winter wheat and barley. However, a fairly considerable part originates from insect pests, attacks of which may be very serious in certain years. Nematodes are important pests in oats, potatoes, sugar beet and legumes. Other pests that have caused yield reductions in monoculture systems during recent years are: aphids, wheat blossom midge (*Contarinia tritici*), pod blossom midge (*Dasineura brassicae*), frit fly (*Oscinella frit*) and blossom beetle (*Meligethes aeneus*).

In several of the reports cited above, emphasis was also placed on the importance of further research into the natural enemies of insect pests, as well as on the possibility of modifying cropping systems and management practices so that a more natural ecological balance is achieved in above ground parts of the crop and the soil.

SOIL ORGANISMS

Soil organisms are those ones which spend a portion of their lives feeding in the soil. Some may spend much of their life above the soil; for instance, certain beetles which prey on aphids. Other aphid predators occur in the soil but leave it to climb up plants to feed. Other soil animals, such as earthworms and certain collembola, spend their entire lives in the soil. Many soil animals are microscopic as are the microflora which consist of fungi, bacteria and actinomycetes. The latter look like fungi but are often considered to be filamentous bacteria. Microflora and other soil organisms are shown in Fig. 1. Interactions between them are also shown, particularly in regard to food web relationships. The direction of food movement, for instance from aphids to predaceous beetles, is shown by arrows. Some animals feed both on living and dead tissue.

Research on soil microflora has covered a wide spectrum of both useful and harmful organisms. On the other hand, research on soil fauna in arable land has almost entirely focused on their role as pests on different crops. In general, there are well developed research units for plant parasitic nematodes and for insect pests. This is quite natural, and the same situation is found wherever agricultural research is conducted.

Alongside this, there have long been smaller research efforts on the more general role of soil organisms and their long-term importance in arable land. By far the largest number of these investiga-

tions have focused on the earthworms (Satchell, 1958, 1982; Edwards & Lofty, 1977).

In recent years, methods of ecosystem analysis developed for the study of natural ecosystems have been applied to the study of arable lands. This approach focuses on the interactions between organisms, injurious and nonpathogenic. It touches on questions concerning biological control but also relates to aspects of arable land productivity.

The organisms living in both agricultural and forest systems have a stabilizing function as they ingest and redistribute matter. Their roles (depending on species) may also be to do with affecting water movement or with their effects as predators. For instance, micro-fungi and bacteria are the primary decomposers invading dead parts of plants and other organic matter substrates such as cattle faeces and, by enzymatic action, changing their chemical composition. These microbial decomposers are fed upon by collembola, certain mites and enchytraeid worms (Fig. 1) which have been found to regulate production of the microflora. Predators may, if abundant enough, have important effects on populations of nonpathogenic (e.g. collembola) and pathogenic organisms (e.g. aphids, noted above, and certain nematodes) alike. Other animals feed directly on the litter as do earthworms which also ingest mineral soil (Fig. 1). These worms may be either shallow or deep-burrowing and the latter may be particularly important in water movement.

Investigations on the fauna of the arable land

International. Comprehensive investigations on the invertebrate fauna of agricultural soil have been conducted in Great Britain at Rothamsted Experimental Station, where, for example, the Park Grass experiments which started in 1856 were utilized. Results have been reported by Edwards & Lofty (1974, 1975) and Edwards (1977). Investigations on the effect of minimal cultivation or direct drilling have been conducted by Henderson (1974), Edwards (1975) and Edwards & Lofty (1977, 1978). Effects of straw residues and burning have also been studied by Edwards & Lofty (1979*a*, *b*). Edwards (1980) has also reported on the influence of the soil fauna on crop seed establishment. Aritajat et al. (1977) have studied the influence of soil compaction on soil fauna. The effects of the above and other agricultural practices were reviewed by Wallwork (1976).

Curry (1979) and Bolger & Curry (1980) have studied the effects on the arthropod fauna in Irish grasslands of heavy applications of slurry.

In West Germany, similar investigations have been conducted by Tischler (1955), for example, comparisons of the abundance of the most important soil fauna groups in grassland compared with arable land under open cultivation. In Poland, a large agro-ecological project has been carried out which has included soil biological investigations (Ryszkowski, 1974).

Among the numerous reports on earthworms, that of Barley (1961) should be mentioned. His report also lists the more important earlier works on earthworms of agricultural soil. Satchell (1958) and Edwards & Lofty (1972) have also reviewed earthworm research. Cotton & Curry (1980*a*, *b*) have carried out investigations on the effects of cattle and pig slurry on numerical density, biomass, community structure and spatial distribution of earthworms.

Some studies concerning the reciprocal relation between earthworms, soil and crop have been carried out by Aldag & Graff (1974), Atlavinyte (1974), Graff & Makeschin (1980) and Ehlers (1975).

The emphasis on research on plant parasitic nematodes has also yielded results that concern non-parasitic groups and relationships between the two categories. The research illustrates clearly the diverse food-web relationships between different groups of soil organisms as well as those within the same animal group, such as nematodes, present in arable soils. Recent additions to the literature include work by Dowe (1970), Mai (1973), Ferris & Ferris (1974), Andrews et al. (1974), Anderson et al. (1978), Beute & Benson (1979) and Andersen, H. J. (1979).

Scandinavia and Finland in particular. In the Nordic countries research has been conducted during recent years along the lines mentioned above. In Denmark, reports have been published on the influence of straw burning on parasitic arthropods (Roesegaard & Lindhardt, 1979), on the influence of reduced soil tillage on soil fauna, and of larger amounts of organic manure (Andersen & Haarlöv, 1977, 1978; Andersen, 1979*a*, *b*, 1980).

Ability of earthworms to resist the toxic effect of pesticides on their enzyme systems, for example, cholinesterase, has been studied in Norway by Stenersen (1981).

Table 1. *Abundance and biomass of soil animal groups in agricultural cropping systems studied by Andrén & Lagerlöf (1983) compared with a Swedish grassland and a coniferous forest ecosystem*

Animal group	Swedish arable land 9 locations		Swedish grassland Spikbole[b]		Swedish pine forest Ivantjärnsheden[c]	
	Mean no. m^{-2}	Biomass[a], mg d w m^{-2}	Mean no.	Biomass	Mean no.	Biomass
Enchytraeid worms	18 000	648	23 800	850	16 200	405
Collembola	51 400	62	108 100	126	60 000	94
Mites	45 800	58	111 900	130	684 400	515
Fly larvae	500	25	5 500	653	780	29
Beetles	200	52	1 400	2 860	440	130

[a] Biomass estimates made after Persson & Lohm (1977). [b] Persson & Lohm, 1977. [c] Persson et al. 1980.

In Finland, the more comprehensive investigations have primarily dealt with the soil surface layer in arable soil: for example, in cereals and leys (Raatikainen, 1966; Raatikainen & Huhta, 1968; Huhta & Raatikainen, 1974). Similar investigations have also been conducted in abandoned arable land by Törmälä & Raatikainen (1976), Törmälä (1977, 1979) and Hokkanen & Raatikainen (1977). Successions of fauna in bark compost and sludge compost have been studied by Huhta et al. (1979).

In Sweden, recent investigations of groups or individual species of soil animals have been conducted in connection with enquiries into possible secondary effects of pesticides (Andrén & Steen, 1978; Lofs-Holmin, 1980, 1981; Nilsson, 1980). In addition, soil fauna investigations have been made in connection with the use of sludge compost (Lagerlöf & Andrén, 1978). Work has also been started on the development of biological control in that the ecology of individual species has been studied with emphasis on the relationship between pests and their natural enemies. At Alnarp, in southern Sweden, work is being conducted (Nilsson, 1981) into the composition of soil fauna in the rhizosphere of sugar beet in order to elucidate the relationships between cultivation technique, use of pesticides and the frequency of attacks by insect pests. Basedow et al. (1981) have investigated the influence of some insecticides, e.g. fenitrothion, on the role of some beetles (family Carabidae) as predators in cereal fields. Borg (1971) investigated the influence of insecticides, among them DDT and lindane, on the abundance of different Collembola species.

The question of soil fauna reactions to extensive use of different kinds of pesticides has recently attracted new interest on account of the programmed cropping of winter cereals (Andersson, Larsson & Kindstrand, 1979). Secondary effects on earthworms have recently been examined by Lofs-Holmin (1982*b*, *c*).

RESEARCH AT SLU 1977–1979

The dearth of data on soil organisms in arable lands in northern Europe led to a project being initiated at the Department of Ecology and Environmental Research. This was entitled "Importance of Soil Organisms for Productivity of Arable Soil: Stage 1. Role of Soil Fauna in Different Cropping and Fertilizing Systems".

The project was planned as a set of three-year investigations with the following objectives:

1. Relationships between cropping systems and distribution and abundance of groups of soil fauna.
2. Importance of different groups of soil fauna in incorporation and decomposition of different types of organic waste in arable soil.
3. Reactions of different soil fauna groups to optimal and superoptimal amounts of fertilizer nitrogen and to some extent, pesticides.

This project utilized the University's existing field trials at different places in Sweden. Of these trials, the long-term rotation and soil fertility trials—sometimes 25–30 years old—were particularly of great value. These existing trials were complemented with new field studies in order to study the aspects listed under the second and third headings above. In addition, a number of small-scale model trials were conducted in the laboratory.

In order to achieve the above three objectives,

an intensive sampling programme was conducted in field experiments of different ages and type from southern to northern Sweden. Altogether there were about 25 field trials. Among the selected trials there was, for example, one with a markedly high population of plant parasitic nematodes, one with severe attacks of cereal root rot, and the 70-year-old fertilizing experiment on the Flahult peat soil. Olof Andrén and Jan Lagerlöf were responsible for potworms, microarthropods, other arthropods and nematodes. Astrid Lofs-Holmin carried out the earthworm studies, apart from those in field experiments started by Inger Bertilsson in 1977 with 6 different organic manures. The results of their investigations have recently been reported by Andrén & Lagerlöf (1980, 1983) and Lofs-Holmin (1982*a*).

Discussion of results

A study of this broad character cannot go deeply into details of taxonomy or interaction between faunal groups in their different roles in the arable soil ecosystem. It must be regarded as a survey, an inventory of the situation in a number of representative cropping or manuring systems in Swedish agriculture.

The methods used to extract the animals from the soil samples also exert a great influence on the results. In this study we have tried to keep the extraction conditions as similar as possible from one occasion to another. This has been possible since small sample units and an automatic computerized control of extraction temperatures have been used.

Another feature of interest is the time lag between experimental treatment and effect, which in some cases has been demonstrated following good timing of the sampling. Abundance figures in one year can be a response of treatment in the preceding year. Thus a positive aftereffect has been demonstrated in the year after farmyard manure addition and ploughing of a perennial grass crop, after an initial negative shock-effect. Dressing with high rates of nitrogen fertilizer or spraying with pesticides may also cause a reduction of soil animal populations directly after the treatment, which can be missed if the sampling is delayed.

In general, the number of animals, especially of Collembola and Pauropoda, are somewhat higher in this study than in several others conducted in arable soils, which may be explained by the efficient extraction method. On the other hand, the numbers are definitely lower in the arable soils studied than in uncultivated permanent grassland soils and forest soils in Sweden (Table 1) (Persson & Lohm, 1977; Persson et al., 1980). Regular disturbances through ploughing, harrowing and sowing of the fields means a less favourable environment for most soil animals than an undisturbed natural biotope. Small, mobile, omniphagous species are favoured. Short generation time and resting stages are also characteristic properties of arable soil dwellers.

The frequency of plant pathogenic animals was low in the experiments studied. Only in one of them was there high population of *Heterodera avenae*, the oat cyst nematode. The abundance of free-living nematodes was not higher here than elsewhere nor were the other groups represented in exceptional numbers. In another experiment, there was an increased level of the pathogenic fungi *Ophiobolus* and *Pseudocercosporella* but quite normal densities of soil animals.

It is difficult to demonstrate correlations between the occurrence of plant pathogens and other faunal groups in the field and indeed it is doubtful whether there are any such correlations. It is more probable that the trophic groups comprising decomposers, omnivores and predators have only very weak relations to the occurrence of pathogenic grazers on below-ground parts of the crops.

Effects of certain treatment. There was a clear relationship between organic matter levels and abundance of soil fauna. This was affected by the intensity of soil cultivation because annual cropping involves high intensity operations which can lead to an increase in soil temperatures which, in turn, will affect rate of breakdown and decomposition of organic matter. These effects are shown in the following examples.

It is well known that perennial grass crops in rotations are of great importance to soil fauna. The plant cover provides shelter for many species of litter dwellers. Such crops build up a large root biomass which, with the litter from above ground parts, provide food for earthworms and certain surface dwelling arthropods. Also, perennial cropping systems allow time for many fauna to recover from the effects of disturbances, e.g. annual ploughing, they experienced under annual crops. Leys, therefore have greater numbers of many faunal groups as was clearly shown in the SLU experiments.

However, the reactions of various taxa to agri-

Table 2. *Mean numbers $m^{-2} \cdot 10^{-3}$ of microarthropods and enchytraeids sampled in cropping systems at Skaftö, August 1979*

	1: Ley		2: Oats		Significant differences
	a: NPK	b: Manure	a: NPK	b: Manure	
Collembola	147.6	225.6	109.0	108.0	1***2, a*b, *i**
Total mites	93.9	112.2	107.9	86.1	
Prostigmatid mites	62.0	50.2	72.1	49.7	
Enchytraeids	36.3	67.7	51.5	52.7	

Significance levels: $p<0.05$=*; $p<0.001$=***; *i* = interaction between treatments.

cultural practices will vary. Andrén & Lagerlöf (1983) found that collemboles were significantly more abundant under grass than under oats although several other groups were not (Table 2). These data my reflect the fact that many of the collembola are surface feeders and respond directly to increases in organic matter in contrast with mites, many of which are predaceous. With regard to earthworms, Lofs-Holmin (1983, see Fig. 2) found that *Lumbricus rubellus* Hoffm. was clearly favoured by longer leys while *Allolobophora caliginosa* Sav. dominated when ploughing was more frequent. These data reflect the different distributions and feeding habits of the two taxa, the former being mainly a surface feeder. Thus, it was abundant when manure was spread on the surface while more *A. caliginosa* were collected when manure was worked into the soil.

After the initial increase in many soil fauna to manure application, a decline in numbers and biomass follows. The populations are still high in comparison with those in cropping systems which did not receive the applications. Much will depend on the soil type. Farmyard manure had greater effects in sandy soils than in ones with a high clay content (Andrén & Lagerlöf, 1983).

There is a clear effect on soil animals when the ley is broken. At first there is a decline in numbers due to animals being buried, some being crushed, and due to the lack of plant cover and drying up of the soil. But, as noted before, increased temperatures will, if soil moisture does not become too low, lead to increased decomposition of dead plant parts. Thus, soil faunal numbers may partially recover. However, if annual crops are grown regularly in the same soil, biological activity will steadily decrease.

The SLU and other studies show that some pesticides can cause a permanent reduction of the soil fauna if pesticides are regularly used. This can be a direct effect of the pesticide or an indirect effect due to change of the plant cover. This latter effect can be very distinct in perennial, long-term grassland, where the floral composition has changed after many years of herbicide application. The direct effect of pesticides will in most cases be temporary if the pesticides are rapidly degraded or only used sporadically.

It is evident then that agriculture based on intensive use of chemical fertilizers without recycling of organic matter or the use of crop rotations which include grass or legume leys may result in degradation of soil faunal communities. These and other possible effects (e.g. Russell, 1977) may be listed as follows:

1. Steady decreases in organic matter levels due to export by harvesting and oxidization.

2. High losses of inorganic N from the soil, e.g. by leaching into the ground water.

3. Decreases in populations of such beneficial organisms as actinmycetes earthworms and predatory arthropods with concomitant increases in pest organisms (see above).

4. Marked deterioration in soil structure due to

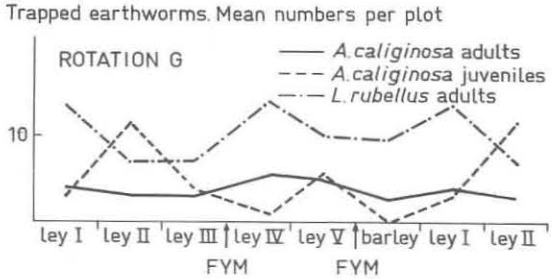

Fig. 2. Numbers of two earthworm species collected during a five year rotation at Röbäcksdalen (from Lofs-Holmin 1983).

(1) and (3) and also because of machine compaction, particularly in clayey soils.

Many questions remain about the above effects and their interrelationships. For instance, do changes in soil faunal populations markedly affect such processes as cyling of organic matter and nutrients? This is presently being evaluated in the second stage of the soil faunal programme at SLU as part of the overall project on Ecology of Arable Land, which is focused on the role of organisms in nitrogen cycling.

Conclusions. A diverse and balanced soil biological community is clearly desirable and possibly even essential for the maintenance of soil fertility. The depletion of the soil fauna which inevitably accompanies arable farming can be minimized by practices which conserve soil organic matter for example the incorporation of ley breaks in arable rotations and the return of crop residues and animal manures to the soil. Thus, current research reinforces traditional belief in the value of mixed farming when crop and animal production compliment one another and complete the organic matter cycle.

REFERENCES

Aldag, R. & Graff, O. 1974. Einfluss der Regenwurmtätigkeit auf Proteinqualität und Proteingehalt junger Haferpflanzen. *Landwirtsch. Forsch 13,* 277–284.

Andersen, C. 1979*a*. Cadmium, lead and calcium content, number and biomass, in earthworms (Lumbricidae) from sewage sludge treated soil. *Pedobiologia 19,* 309–319.

Andersen, C. 1979*b*. The influence of farmyard manure and slurry on the earthworm population (Lumbricidae) in arable soil. *Proc. VII Int. Colloq. Soil Zool.*

Andersen, C. 1980. The influence of climatic conditions on activity and vertical distribution of earthworms in a Danish arable soil. *K V Landbohöjsk. Årsskr. 1980,* 57–68.

Andersen, C. & Haarlöv, N. 1977. Jordbundsfauna i markjord- ved reduceret jordbehandling. *BP Nyhedstjeneste, 28:* 86, 6–10.

Andersen, C. & Haarlöv, N. 1978. Agermarkens fauna. *Ugeskr. Agron. Hortic. Forst. Lic. 1978:* 17, 6 s.

Andersen, H. J. 1979. Migrerande rodnematoder i danske bygmarker. *Tidskr. Planteavl 83,* 1–72.

Anderson, R. V., Elliot, E. T., Mc Clellan, J. F., Coleman, D. C., Cole, C. V. & Hunt, H. W. 1978. Trophic interactions in soils as they affect energy and nutrient dynamics. III. Biotic interactions of bacteria, amoebae and nematodes. *Microb. Ecol. 4,* 361–371.

Andersson, K., Larsson, N. G. & Kindstrand, U. 1979. Försök med programmerad odling av höstvete 1979. *Skånskt lantbruk 12,* 441–450.

Andrén, O. & Lagerlöf, J. 1980. The abundance of soil animals (Microarthropoda, Enchytraeidae, Nematoda) in a crop rotation dominated by ley and in a rotation with varied crops. In Dindal, D. (ed.), *Soil biology as related to land use practices. Proc. 7th Int. Soil Zool. Colloq.,* 274–279. Washington D.C.: E.P.A.

Andrén, O. & Lagerlöf, J. 1983. Soil fauna (microarthropods, enchytraeids, nematods) in Swedish agricultural cropping systems. *Acta Agric. Scand. 33.*

Andrén, O. & Steen, E. 1978. Bekämpningsmedlens inverkan på markens organismer. 1. Djurlivet. *Statens naturvårdsverk, PM 1082.* 95 pp. Stockholm.

Andrews, R., Coleman, D. C., Ellis, J. E. & Singh, J. S. 1974. Energy flow relationships in a shortgrass prairie ecosystem. *Proc. first Int. Congr. Ecol. 22–28 The Hague, Sept. 8–14.*

Aritajat, U., Madge, D. S. & Gooderham, P. T. 1977. The effects of compaction of agricultural soils on soil fauna. I. Field investigations. *Pedobiologia 17,* 262–282.

Atlavinyte, O. 1974. Effect of earthworms on the biological productivity of barley. *Lietuvos TSR Mosklu akad. darbai ser C. 1,* 69–79.

Barley, K. P. 1961. The abundance of earthworms in agricultural land and their possible significance in agriculture. *Ad. Agron. 13,* 249–268.

Basedow, Th., Borg, Å. & Scherney, F. 1981. Auswirkung von Insektizidbehandlungen auf die epigäischen Raubarthropoden in Getreidefeldern insbesondere die Laufkäfer (Coleoptera, Carabidae). *Acta Agric. Scand. 31,* 153–164.

Beute, M. K. & Benson, D. M. 1979. Relation of small soil fauna to plant disease. *Annu. Rev. Phytopathol. 17,* 485–502.

Bolger, T. & Curry, J. P. 1980. Effects of cattle slurry on soil arthropods in grassland. *Pedobiologia 20,* 246–253.

Borg, Å. 1971. Några undersökningar över kollembolae (Collembola) i åkerjord och deras påverkan av pesticider. *Statens växtskyddsanst Medd. 15 (137),* 53–85.

Cotton, D. C. F. & Curry, J. P. 1980*a*. The effects of cattle and pig slurry fertilizers on earthworms (Oligochaeta, Lumbricidae) in grassland managed for silage production. *Pedobiologia 20,* 181–188.

Cotton, D. C. F. & Curry, J. P. 1980*b*. The response of earthworm populations (Oligochaeta, Lumbricidae) to high applications of pig slurry. *Pedobiologia 20,* 189–196.

Curry, J. P. 1979. The arthropod fauna associated with cattle manure applied as slurry to grassland. *Proc. R Ir Acad. Sect. B. Vol. 79, B. No. 2.*

Dindal, D. (ed.). 1980. Soil biology as related to land use practices. *Proc. 7th Int. Coll. Soil Zool., Syracuse, N.Y. USA.*

Dowe, A. 1970. Zur Rolle der Nematoden innerhalb der Bodenfauna. *Wiss. Z. Univ. Rostock 19 Jahrg. Mat.—Naturwiss. Reihe, 8,* 587–590.

Ebbersten, S. 1980. Optimerad växtodling III. Ett försök till analys av dagens diskussion om olika växtodlingssystem. *K. Skogs- o. LantbrAkad. Tidskr. 119,* 367–389.

Edwards, C. A. 1975. Effects of direct drilling on the soil fauna. *Outlook Agric. 8,* 243–244.

Edwards, C. A. 1977. Investigations into the influence of agricultural practice on soil invertebrates. *Ann. App. Biol. 87,* 515–520.

Edwards, C. A. 1980. The influence of the soil fauna on crop seed establishment. *MAFF/ADAS Ref. Book 321 Agron. Conf. Malvern 1979,* 38–42. London.

Edwards, C. A. & Lofty, J. R. 1972. *Biology of earthworms.* 339 pp. London: Chapman & Hall.

Edwards, C. A. & Lofty, J. R. 1974. The invertebrate fauna of the Park Grass Plots. I. Soil fauna. *Rothamsted Rep. 1974, Part 2,* 133–154.

Edwards, C. A. & Lofty, J. R. 1975. The influence of cultivations on soil animal populations. *Proc. V. Int. Coll. Soil Zool. 1973,* 399–407.

Edwards, C. A. & Lofty, J. R. 1977. The influence of invertebrates on root growth of crops with minimal or zero cultivation. *Ecol. Bull. (Stockholm) 25,* 348–356.

Edwards, C. A. & Lofty, J. R. 1978. The influence of arthropods and earthworms upon root growth of direct drilled cereals. *J. Appl. Ecol. 15,* 789–795.

Edwards, C. A. & Lofty, J. R. 1979*a*. The effects of straw residues and their disposal on the soil fauna. In Grassbard, E. (ed.), *Straw decay and its effect on utilization and disposal,* 37–44. Chichester: J. Wiley & Sons Ltd.

Edwards, C. A. & Lofty, J. R. 1979*b*. The effects of strawburning on the soil fauna. *ADAS Rep. Straw Utilization Con., Oxford,* 45–50.

Ehlers, W. 1975. Observations on earthworm channels and infiltration on tilled and untilled loess-soil. *Soil Sci. 119,* 242–249.

Ferris, V. R. & Ferris, J. M. 1974. Interrelationships between nematode and plant communities in agricultural ecosystems. *Agro-Ecosystems 1,* 275–299.

Graff, O. & Makeschin, F. 1980. Beeinflussung des Ertrags von Weidelgras (*Lolium multiflorum*) durch Ausscheidungen von Regenwürmern dreier verschiedener Arten. *Pedobiologia 20,* 176–180.

Henderson, J. F. 1974. Invertebrates and pasture productivity. *Rothamsted Exp. St. Rep. 1973, Part 1,* 201–202.

Hokkanen, H. & Raatikainen, U. 1977. Faunal communities of the field stratum and their succession in reserved fields. *J. Sci. Agric. Soc. Finland 49,* 390–405.

Huhta, V. & Raatikainen, U. 1974. Spider communities of leys and winter cereal fields in Finland. *Ann. Zool. Fenn. 11,* 97–104.

Huhta, V., Ikonen, E. & Vilkamaa, P. 1979. Succession of invertebrate populations in artificial soil made of sewage sludge and crushed bark. *Ann. Zool. Fenn. 16,* 223–270.

Jansson, S. L. 1975. Bördighetsstudier för markvård. Försök i Malmöhus län 1957–74. *K. Skogs o. LantbrAkad. Tidskr. Suppl. 10.* 60 pp.

Kornher, A. & Nyström, S. 1974. *Växtföljder vid olika driftsinriktning* (Rapp. och avh. 7. Inst. f. växtodling, Lantbrukshögskolan). 71 pp. Uppsala.

Lagerlöf, J. & Andrén, O. 1978. Markbiologiska undersökningar inom Laxåprojektet. *Statens Naturvårdsverk PM 1094.* 43 pp. Stockholm.

Lofs-Holmin, A. 1980. Measuring growth of earthworms as a method of testing sublethal toxicity of pesticides. *Swedish J. agric. Res. 10,* 25–33.

Lofs-Holmin, A. 1981. Influence in field experiments of benomyl and carbendazim on earthworms (Lumbricidae) in relation to soil texture. *Swedish J. agric. Res. 11,* 141–147.

Lofs-Holmin, A. 1982*a*. Earthworm population dynamics in different agricultural rotations. Darwin Centenary Symposium Grânge over-Sands. In Satchell, J. E. (ed.), *Earthworm ecology.* London: Chapman & Hall.

Lofs-Holmin, A. 1982*b*. Measuring coccon production of the earthworm *Allolobophora caliginosa* (Sav.) as a method of testing sublethal toxicity of pesticides. An experiment with benomyl. *Swedish J. agric. Res. 12,* 117–119.

Lofs-Holmin, A. 1982*c*. Influence of routine pesticide spraying on earthworms (Lumbricidae) in field experiments with winter wheat. *Swedish J. agric. Res. 12,* 121–123.

Lofs-Holmin, A. 1983. Influence of agricultural practices on earthworms. *Acta Agric. Scand. 33.*

Lohm, U. and Persson. T. 1977 (eds.). Soil Organisms as Components of Ecosystems. Proc. 6th Int. Coll. Soil Zool. *Ecol. Bull. (Stockholm) 25.* 614 pp.

Mai, W. F. 1973. Ecology of soilinhabiting and plant-parasitic nematodes. *Proc. Soil Microcommunities Conf. 1973,* 84–87.

Nilsson, C. 1980. Effekter av syntetiska pyretroider på nyttoinsekter. *Växtskyddsrapporter, jordbruk 12,* 76–82.

Nilsson, C. 1981. Resultat från insekticidförsök. Betodlaren 2, 132–134.

Nyström, S. 1976. *Resultat från några långvariga växtföljdsförsök i Skåne* (Rapp. och avh. 43. Inst. f. växtodling, Lanbrukshögskolan). 39 s. Uppsala.

Olsson, P. 1976. *Specialundersökningar i växtföljdsförsök med ensidig stråsädesodling.* (Rapp. och avh. 41. H 1–8, Inst. f. växtodling, Lanbrukshögskolan). Uppsala.

Persson, T. & Lohm, U. 1977. Energetical significance of the Annelids and Arthropods in a Swedish grassland soil. *Ecol. Bull. (Stockholm) 23.* 211 pp.

Persson, T., Bååth, E., Clarholm, M., Lundkvist, H., Söderström, B. E. & Sohlenius, B. 1980. Trophic structure, biomass dynamics and carbon metabolism of soil organisms in a Scots pine forest. In Persson, T. (ed.), Structure and function of northern coniferous forests. An ecosystem study. *Ecol. Bull. (Stockholm) 32,* 419–459.

Raatikainen, U. 1966. The effect of stubble height of spring cereals on certain pests. *Ann. Agric. Fenn. 5,* 1–5.

Raatikainen, M. & Huhta, V. 1968. On the spider fauna of Finnish oat fields. *Ann. Zool. Fenn. 5,* 254–261.

Roesegaard, H. & Lindhardt, K. 1979. The effect of straw burning on predaceous arthropods of the soil surface. *Danish J. Plant Soil Sci. 83,* 305–323.

Russell, E. W. 1977. *Soil conditions and plant growth,* 10th ed. London: Longman.

Ryszkowski, L. (ed.). 1974. *Ecological effects of intensive agriculture*. Warsaw: Polish Scientific Publishers.
Satchell, J. E. 1958. Earthworm biology and soil fertility. *Soils Fert. 21,* 209–219.
Satchell, J. E. (ed.). 1958. *Earthworm ecology*. London: Chapman & Hall.
Stenersen, J. 1981. The mode of action of cholinesterase-inhibiting pesticides on earthworms toxicity, inhibition of cholinesterases and degradation. *Norw. Plant Prot. Inst. Division of Entomol.* Ås. Norway. 13 pp. (Diss.).
Tischler, W. 1955. Effect of agricultural practice on the soil fauna. In Kevan (ed.), *Soil zoology,* 215–230. London.
Törmälä, T. 1977. Effects of mowing and ploughing on the primary production and flora and fauna of a reserved field in Central Finland. *Acta Agric. Scand. 27,* 253–264.
Törmälä, T. 1979. Numbers and biomass of soil invertebrates in a reserved field in Central Finland. *J. Sci. Agric. Soc. Finland 51,* 172–187.
Törmälä, T. & Raatikainen, U. 1976. Primary production and seasonal dynamics of the flora and fauna of the field stratum in a reserved field in Middle Finland. *J. Sci. Agric. Soc. Finland 48,* 363–385.
Vaněk, J. (ed.). 1975. Progress in soil zoology. *Proc. 5th Int. Coll. Soil Zool. Prague 1973.* 630 pp.
Wallwork, J. A. 1976. *The distribution and diversity of soil fauna*. 355 pp. London: Academic Press.

MS. received 18 November 1982

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